POLLUTION CONTROL AND MINESITE REHABILITATION IN SURFACE COAL MINING

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INTRODUCTION

Large scale open-pit, strip or surface mining in Australia, South Africa, United States, Canada and eastern Germany has large impacts on the environment. These include large voids, overburden dumps, coal washery wastes, contaminated surface and groundwater, spontaneous combustion, dust, destruction of native ecosystems, alienation of rural lands and infrastructure. These impacts may be absent or greatly reduced where the coal mining is on a smaller-scale and less mechanised.

Three issues which are common to all mines are:

- dust (and other aerial contaminants)
- water quality and management
- rehabilitation of disturbed lands

each of which is discussed below. The descriptions are generic as the author has not at the time of writing had the opportunity of visiting the coalmines in Vietnam.

DUST SUPPRESSION

Dust is derived from:

- drilling and blasting
- road surfaces disturbed by vehicles
- materials handling and comminution e.g. hoppers, conveyor belts, crushing and grinding
- surfaces of minewaste dumps (overburden, washery wastes, tailings etc)
- unrehabilitated minesites, and
- spontaneous combustion

Dust generation is more of an issue in the semi-arid to arid environments of Australia and South Africa than the more humid climates of Canada, United States, Europe and Asia. Its most significant impact is on human health, particularly bronchial and pulmonary infections, but may also restrict plant growth by covering leaves, contaminate soils and surface waters and degrade visual impacts.

Common terminology to describe dust is:

- Nuisance dust - generally used to describe that dust which reduces environmental amenity without necessarily resulting in material environmental harm;
- Fugitive dust - refers to that derived from a mixture or not easily defined sources such as vehicular traffic, materials transport and handling and unvegetated surfaces;
- Inhalable dust - is that fraction of total airborne particles which is inhalable through the nose and mouth, with about 80% being 2.5-10µm in diameter;
- Respirable dust - is that dust with diameters less than 2.5µm which penetrates to unciliated airways of the lungs.

Common dust control practices used at coal and metalliferous mines in Australia are:

- Water - this can take the form of submerged tailings and washery wastes or the application of water to troublesome areas.
- Soil erosion prevention techniques - the method relies on the use of physical obstacles to increase surface roughness and lower the surface to below the saltation threshold.
- Rock armour - use of waste rock to shelter the surface from wind (and water). The surfaces may also be re-vegetated.
- Surface treatments - these involve spraying the surfaces with materials which act to form a skin on the surface. Bitumen and proprietary liquids have been used. The long-term durability and cost of these materials remain an issue.
- Re-vegetation.
- Revised drilling and blasting techniques to utilise meteorological data as well as mine data.
- Covering of all forms of transport including trucks, conveyer belts etc.

A less commonly recognised source of dust is smoke derived from spontaneous combustion of coal stock-piles and minewastes. Spontaneous combustion is caused by oxidation of coal particles to produce heat and is accelerated by oxidation of pyrite or marcasite. The rate of oxidation is dependent on particle size, the nature of the coal, temperature and oxygen concentration. There are gaseous products such as CO_2, CO, CH_4, NO_x and SO_3 together with particulate polynuclear aromatic hydrocarbons (PAH's).

Two recent publications which provide an overview of dust in mining are:

- The Environmental Effects of Dust from Surface Mineral Workings, Volumes 1 and 2. Department of the Environment (Minerals Division), HMSO
- Environment Australia's Best Practice Environmental Management in Mining - Dust Control, by Howard and Cameron.

In addition the publication

- Environmental Management in the Australian Minerals and Energy Industries, Principles and Practices (1996) Ed. D. Mulligan

provides a number of papers on environmental issues including dust.

Application of water is probably the most cost-effective technique for dust suppression. However, care must be taken as to the quality of water used. It is common to use mine water as it is of minimal alternative use, but may well contain contaminants such as heavy metals, sulfate or salt which may inflict greater environmental damage than the dust.

Of greatest significance is the rehabilitation of disturbed lands which is described in detail below.

WATER QUALITY AND TREATMENT

Prior to the development of technologies to treat contaminated water, it is necessary to ascertain the source of water at a minesite and the nature of contaminants. There are two excellent publications addressing water management:

- Environment Australia's Best Practice Environmental Management in Mining - Water Management, by Joy, Jones and McQuade
- Minerals Council of Australia - Minesite Water Management Handbook (1997)

together with the previously cited volume by Mulligan.

For minesite water management, the relevant hydrological processes are:

- Precipitation - which will vary seasonally but also randomly with weather variations.
- Infiltration - many factors influence the rate of rainfall infiltration into soil and other geological materials including the saturated hydraulic conductivity, its initial moisture content, soil surface condition and nature of rainfall events.
- Surface run-off - where infiltration is low, surface run-off is increased which leads to erosion and high suspended load.
- Evapotranspiration - is the process where vegetation extracts water from the soil profile and respire it as water vapour. The rate is dependent on the humidity and therefore the climate. Because vegetation reduces soil moisture, removing the vegetation tends to reduce water volumes the soil can hold which then leads to increased run-off.
- Evaporation - is very much dependent on the climate. It is of great importance to the mining industry as it represents a loss of water from surface storage and may be used as a management measure to reduce surplus water volumes.
- Percolation - is the movement by gravity of water already in the soil mass to recharge groundwater aquifers.
- Streamflow - is the directed flow of surface water in defined channels which are commonly disrupted by mining activities.
- Groundwater flow - is the flow of water within aquifers beneath the surface. The flow is dependent on the hydraulic head and characteristics of the aquifer.

Apart from precipitation, the hydrological processes are commonly disrupted by mining activities, which together with the following contaminants having a marked impact on the environment.

Rainwater and natural surface and groundwaters have their own characteristics including:

- Dissolved and particulate constituents - partitioning of elements between the dissolved and particulate phases is dependent on physico-chemical characteristics and are generally separated by filtering through 0.45µm pore size filter.
- Organic acid and carbonate water systems - fresh waters are dominated by two geochemical systems

  – water in which the carbonic acid equilibrium is dominant
  – water in which there is a high level of dissolved organic matter.

- pH - is an indicator of the intensity of the acidic or basic character of the water. Most natural waters have a pH range of 5.5 - 8.5.
- Alkalinity - refers to the acid neutralising capacity (pH buffering) of water i.e. its ability to reduce changes in pH brought about by addition of an acid.
- Hardness - is a measure of the Ca^{2+} and Mg^{2+} concentration and is normally of little concern at minesites.
- Conductivity - usually expressed as EC in m^{s}/m and is a measure of the total dissolved solids and therefore of the level of contamination.
- Solids - is a combination of total dissolved solids (TDS) and total suspended solids (TSS). The latter are the particulates which are derived by erosion.
- Turbidity - is a measure of the ability of TDS and colloids to scatter light.
- Oxygen Demand - dissolved oxygen is a key water quality parameter required to sustain a healthy aquatic ecosystem. It is sometimes measured as Eh (in millivotts) which reflects the redox potential of the water.

The processes of mining will change these basic parameters through the addition of

- Anions and Cations - such as the anions Cl^- HCO_3^- OH^- SO_4^{2-} CO_3^{2-} PO_4^{3-} and cations Na^+ K^+ Ca^{2+} Mg^{2+} Fe^{2+} Fe^{3+}. The sources of these ions are leachates from minewastes and surrounding rocks.
- Heavy and Trace Metals - in general these are defined as those elements which are ecotoxic and include Al, Mn, Cr, Cu, Zn, As, Se, Cd, Sb, Ba, Hg, Tl, Pb, Bi, U and Th, which are commonly derived from sulfide minerals and country rocks.
- Nutrients - most commonly N and P which are essential to sustaining adequate biological function. Excess concentrations lead to algal blooms and macrophytes.
- Oils, greases and hydrocarbons.
- Organics - the most common source are the various reagents used in froth flotation. The effects of these and their breakdown products on the environment is not well understood.
- Chemicals - many chemicals are used in the mining and processing of minerals. These include cyanide, sulfuric acid, caustic soda all of which have significant environmental impact if entering the hydrological cycle.
- Radionuclides - some minerals including coal contain radionuclides (mainly U and Th) which may enter waters but in very low concentrations.

At coal mines, the most significant contaminants are suspended materials and lowering of pH and increased acidity, sulfate and heavy metal concentrations resulting from acid drainage (AMD). Other contaminants include oils, greases, hydrocarbons and chemicals. The issue of particulates derived from dust has been addressed above. However, care must be exercised to ensure that water used to suppress dust does not flow into natural water courses adding to suspended and dissolved loads. In particular, saline waters (very common in Australia) may lead to salination of surroundings. A far greater source of suspended particulates is erosion of minewastes, exposed land and roadways.

By far the greatest concern at minesites is the oxidation of sulfide minerals (pyrite, pyrrhotite, marcasite are the most common) to form acid drainage (AMD). The most common sources are the sulfides left in minewastes, underground mines or the walls of open-pits which are oxidised by atmospheric oxygen, in the presence of moisture. As a result the pH may decrease to 2, and the SO_4^{2-} and Fe^{2+} concentrations increase. These changes may be ecotoxic, but by far the greatest concern is the solubilisation of heavy metals associated with the sulfides and other elements, particularly Al and Mn from the acceleration breakdown of the gangue minerals. Algal blooms, contaminated waters and soils, aquatic ecotoxicity and entry into the food chain may result.

Another consequence of the accelerated break-down of gangue minerals is potentially increased erosion rates, weakened minewaste structures (tailings dam walls and waste rock dumps) and catastrophic siltation of waterways.

There are many references to the causes, impacts and management of AMD including:

- Environment Australia's Best Practice Environmental Management in Mining - Managing Sulphidic Mine Wastes and Acid Drainage, by Johnston, Murray and Ritchie.
- Proceedings of International Conferences on Acid Rock Drainage.
- Proceedings of Australian Acid Mine Drainage Workshops

and the publication by Mulligan.

The technology used to treat contaminated water is dependent on the nature of the contaminants. There are four commonly used technologies:

- Sediment basins provide a simple form of physical treatment to reduce the level of suspended solids in surface run-off. Ideally, sediment basins should be used in conjunction with a soil erosion management plan.
- Wetlands treat waters passing through them both physically and biologically and can improve the water quality by raising the pH, removing sediments, nutrients and heavy metals.
- Chemical treatment is part of ore processing operations and is most commonly used to neutralise AMD and precipitate contaminant elements. Chemical treatment is expensive compared with other treatments.
- Evaporation ponds are used to dispose of excess water in climates where evaporation exceeds precipitation. As a result of evaporation, contaminants will be precipitated out.

A relatively new technology is recharge to groundwater where it is known that the groundwater is already contaminated, is in a confined aquifer and will not be used for agricultural purposes or human consumption.

An essential part of water management is continual monitoring of hydro-meteorological, water quality and biological parameters. This provides:

- reliable pre-mining baseline data to use as an objective yardstick when assessing the impact of mining operations on hydrological processes
- data to design physical and process elements of water management system
- regular data to verify effectiveness of management systems, and
- information of consequences of any incident affecting water quality.

MINESITE REHABILITATION

The rehabilitation of minesites should ideally be planned before any mining commences using the data provided by exploration. In particular, the data should include physical, chemical, hydrological and geotechnical properties of the ore (coal), gangue and country rocks to develop an Environmental Management Plan (EMP). An EMP is also necessary for operational mines to ensure that the best result is achieved and that the community and regulatory authorities are satisfied.

Factors which must be considered are:

- physical and chemical stability of minewaste dumps and open-pits
- maintenance of water quality
- safe disposal of infrastructure
- development of sustainable ecosystems, and
- meeting community expectations

Relevant references include:

- Environment Australia's Best Practice Environmental Management in Mining - Rehabilitation and Revegetation by Ward
- Environment Australia's Best Practice Environmental Management in Mining - Landform Design for Rehabilitation by Lindbeck and Hannan
- Environment Australia's Best Practice Environmental Management in Mining - Community consultation and Involvement by O'Neill and St. Clair
- Environment Australia's Best Practice Environmental Management in Mining - Tailings Containment by Cooling and Lewis

and the volume edited by Mulligan.

Previous rehabilitation usually involved covering with benign waste rock and soil and then planting trees or grasses - out of sight, out of mind approach. It is now known that this approach is not appropriate. Presently used technologies require detailed knowledge of the reasons for rehabilitation, characteristics of covering materials and wastes, climate, and local ecology.

It is not possible to describe rehabilitation techniques for all coal mines, particularly the open-pits left after surface mining as they vary in depth from a few to 150+ metres. Although more of a safety than an environmental issue, ensuring the stability of the pit walls is essential. Water passing over pit walls will collect in the pit and contain suspended or dissolved solids. Pit water quality is of importance if the water is to be utilised or enters the groundwater flow. If the pit walls contain pyrite, AMD may result causing serious degradation of water quality. In Australia, some open-pits have been filled with water and are used for recreational purposes. Rehabilitation of minewastes commonly involves reshaping to reduce erosion, covering with benign material (waste rock, clay, topsoil) and development of an ecosystem which is consistent with the end use. In some climatic regimes it will be necessary to armour the surface with rocks, tree branches or chemical covers to prevent water and wind erosion. Eventually revegetation will act to prevent erosion.

As previously indicated, AMD is probably the greatest environmental issue facing the mining industry. It is caused by the oxidation of sulfides in minewastes and mines. To prevent, or at least reduce its impact, it is necessary to exclude oxygen (thus preventing oxidation) or alternatively prevent water transporting the oxidation products to the surrounding environment. Exclusion of oxygen is difficult and is best achieved by placing sulfidic minewastes under water such as in lakes, the ocean or flooding with water. Where evaporation exceeds precipitation it is possible to design a ‘dry’ cover of clay which remains saturated preventing oxygen infiltration.

Covers can be shaped to shed water but care must be taken to prevent erosion during heavy rainfall events. Another technique is to design a cover which acts as a “storage-release” system which is able to store any precipitation during the ‘wet’ season and release it by evapotranspiration during the ‘dry’. To be effective, the cover materials must be well characterised, which involves knowledge of soil physics. A far more expensive solution is to cover the minewastes with sheets of heavy duty plastic. Both techniques are very much dependent on retaining the integrity of the cover which is doubtful if trees are planted on the cover. Roots may allow ingress of both water and oxygen.

Where sulfidic minewastes have been emplaced for long periods, oxygen and water will be incorporated and it will not be possible to prevent AMD. It is therefore necessary to treat the seepage. If the seepage is of low volume, it is possible to increase the water quality by passing through anoxic limestone drains. For larger volumes, passing the contaminated water through a constructed or natural wetland is a technique used throughout the world. It should be noted that removal of sulfate by sulfate reducing bacteria will probably only occur in mature wetlands. Another concern is the long-term capability of wetlands. For larger volumes, neutralisation with lime or limestone in large dams or in neutralisation plants not only increases the pH but causes precipitation of contaminant elements with the neutralisation sludge. Although very effective, it is costly, and safe disposal of the sludge is often a problem.

Before mining starts it is commonly necessary to remove trees and shrubs as well as the topsoil. These should be stock-piled for future use during rehabilitation. The vegetation contains seeds for natural revegetation and serves as hosts for a range of organisms and fauna which are part of the native ecosystem. Stock-piling the soil for extended periods may result in sterilisation of contained flora and fauna. Under no circumstances should the cleared vegetation be burnt.

Research in Australia has developed indicators of sustainable ecosystem establishment. The technique involves quantitative measurement of soil characteristics and although used in the semi-arid to arid regions of Australia, is readily applicable elsewhere. The technique is now widely used to assess the success of rehabilitation at minesites.

The nature of rehabilitation is dependent on the intended land use, which may be dependent on community wishes or expectations. Uses include reversion to natural state, agriculture, grazing, recreation, industry or urban development. Each of these will require that contamination is minimised, particularly of the soil and water.

CONCLUSIONS

Mining has a marked effect on the environment. Environmental management at established mines is more expensive and difficult than if a management plan had been implemented prior to commencement of mining. Planning for impacts such as dust, water quality remediation and rehabilitation are dependent on the detailed knowledge of ore and its host rocks, as well as the hydrology, geomorphology and ecosystems of the site. Of even greater importance is to ensure that all people employed by the mine as well as the local community are in agreement with the aims and strategies of any environmental management techniques employed.